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WINTER WHEAT RESPONSE TO WATER AND NITROGEN IN THE NORTH AMERICAN GREAT PLAINS*

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ABSTRACT

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A unique, identical experiment was conducted at 5 locations in the North American Great Plains, from Alberta, Canada to Texas, U.S.A., in 1985 and 1986, to investigate the response of winter wheat (*Triticum aestivum* L.) to water and nitrogen fertility treatments under these climatic regimes. The experimental design consisted of 4 nitrogen levels, 3 irrigation regimes, 2 cultivars, with 4 replications. One cultivar, Colt, was common to all locations. Crop response throughout the growing season was monitored by intensive plant sampling, measuring spectral reflectance, evaluating canopy temperature, and by detailed measurements of the microclimate and of soil water content. This paper discusses the procedures common to all locations. The papers which follow in this issue present the results of these experiments, each paper treating a different aspect of the experiment across locations.

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INTRODUCTION

In 1983, a joint research program was initiated between the U.S.A. and the People's Republic of China to study factors that affect agricultural productivity in similar regions of the North American Great Plains and the North China Plain. One project within the program was to study the response of winter wheat to water and nitrogen levels under different environmental conditions. Consequently, an experiment was conducted at 5 locations in the North American Great Plains and at 2 locations in the North China Plain.

Water–fertility–environment interactions on plant growth have been studied for many decades, but, generally, these studies have been conducted at one location for a number of years, in order to look at the effect of climatic variability. Studies involving different locations have taken place over a limited latitude range and have usually been concerned with developing water-production functions.

Soil fertility varies widely over the Great Plains as discussed by Jackson et al. (1983). They stated that the yield response of crops to fertilizer in dryland (rain-fed) agriculture was primarily dependent upon stored available soil water at or near planting and rainfall during the growing season. Thus, yield increases from applied fertilizer are not always uniformly realized in the Great Plains.

Brown (1971) reported that fertilized wheat extracted more soil water and at a higher rate than unfertilized wheat in Montana. The increase in yield resulted in an increased water-use efficiency with applied N. In his study the application of N caused more extraction of available soil water from deeper in the soil profile and there was less residual soil water at the end of the growing season. Rickman et al. (1978) examined water-use relative to rooting profiles and concluded that peak water-use rates were not coincident with the maximum leaf area but occurred just prior to anthesis. At that stage of growth the maximum root sink was present. Further investigation of the role of roots and the pattern of water uptake may provide a better understanding of the response of different cultivars to dryland environments. Similarly, Sharma and Chaudhary (1983) reported that water uptake in wheat increased with root density, depending on root age and soil water availability. They concluded that deep (0.3 m) placement of N in a loamy soil under rainfed conditions allowed a more efficient root system to develop with a positive impact on growth and yield. They reported a yield increase of 38%. Karim and Dregne (1981) found that addition of N, P and K dramatically increased root dry weight in sorghum.

Campbell and Davidson (1979a) in a controlled-environment study on spring wheat found that dry-matter accumulation was proportional to fertilizer N applied and inversely related to temperature. They also showed that early season stress slowed dry-matter accumulation but not as severely as a late stress during anthesis. Water use was directly proportional to the amount of N applied but was not influenced by temperature, when the amount of water used increased by 52% from 44 to 132 kg ha^{-1} N applied. Grain yield also increased with applied N. The increase was the same whether water stress was low throughout the growth cycle or was imposed during tiller development up until the flag leaf emerged. As the N level increased from 44 to 132 kg ha^{-1} grain yield increased linearly by 236% (Campbell and Davidson, 1979b). This effect may be due to the low air temperatures throughout the entire growing season. In Australia, Cooper (1980a), found that the addition of 112 kg N ha^{-1} under dryland conditions had little effect on the yield and no effect on the crop water use. The reason for this lack of response was attributed to the high soil fertility at the onset of the experiment (Cooper, 1980b). Water-use efficiency for this study was comparable with other reported values at 10.4 kg ha^{-1} mm^{-1}. In water–fertility studies with spring wheat in North Dakota, Bauer (1980) and Bauer et al. (1985) reported water-use efficiencies ranging from 1.8 to 11.6 kg ha^{-1} mm^{-1} and that water-use efficiency was increased by fertilizer N when grain yields were increased. Black (1982) also reported that water-use efficiency was increased when grain yields were increased from application of fertilizers.

The purpose of this series of papers is to report the results for the response of winter wheat to different soil water, nitrogen and climatic regimes. This introductory paper describes the overall experiment and sets the stage for reporting the results. A multi-location, 2-year, experiment was identically conducted on the North American Great Plains, according to the experimental procedures herein described. This paper is followed by 7 presentations which discuss the results of specific analyses of the experimental data across all locations. Topics include: the difference in climate between locations and years; the treatment effects on yield and its components; canopy temperature; spectral reflectance; crop phenology; biomass production; water-use efficiency. Data from the sites in the North China Plain are not available for inclusion in this report.

LOCATIONS

The 5 locations for the experiment were chosen in the North American Great Plains based on the expertise at those locations and the latitude within the Plains.

Location	Latitude	Longitude	Elevation	Soil type
1. Lethbridge, AB	49°42′N	112°50′W	920 m	Lethbridge silty clay loam
2. Mandan, ND	46°46′N	100°55′W	549 m	Williams loam
3. Tryon, NE	41°37′N	100°50′W	975 m	Valentine fine sand
4. Manhattan, KS	39°09′N	96°37′W	321 m	Muir silt loam
5. Lubbock, TX	36°31′N	109°03′W	1830 m	Olton clay loam

The soil types are classified below.

Soil type	Classification
1. Lethbridge silty clay loam	Typic Haploborolls
2. Williams loam	Typic Argiborolls
3. Valentine fine sand	Typic Ustipsaments
4. Muir silt loam	Cumulic Haplustolls
5. Olton clay loam	Aridic Paleustolls

EXPERIMENTAL DESIGN AND TREATMENTS

Design

The variables in the field experiment were soil water level, available nitrogen (NO_3) content, and winter wheat cultivars. A split–split plot experimental design was used for 3 water levels (W1, W2, W3) as the main plots, four NO_3-N levels (N1, N2, N3, N4) as subplots, and two cultivars (C1, C2) as sub-subplots (Fig. 1).

Water level was not randomized within the 4 replications (R), but NO_3-N levels were randomized within water levels, and cultivars were randomized within NO_3-N levels. Because water levels were not randomized, the error associated with R*W was not valid. The remaining errors (N*W, R*N and R*N*W) and (R*C, R*C*W, R*C*N and R*C*N*W) were valid for tests of

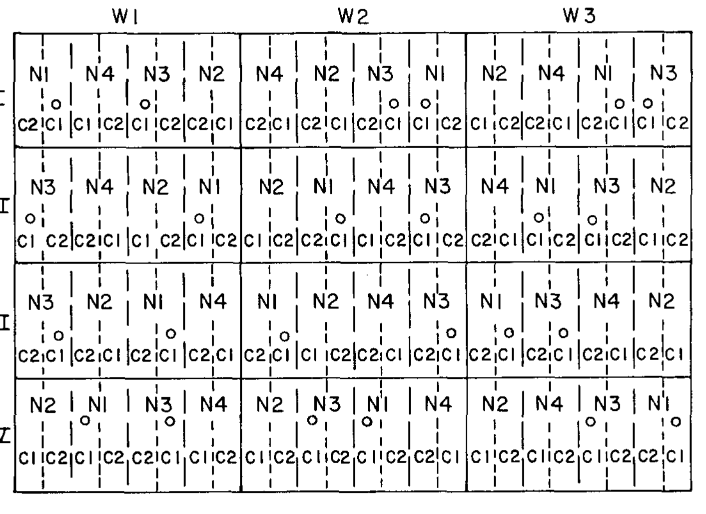

Fig. 1. Arrangement of plots to measure the response of two wheat cultivars (C) to water (W) and nitrogen (N), and location of neutron access tubes (o).

significance for nitrogen levels and cultivars, as well as for their interactions including those with water.

Soil water level

W1 – represents dryland (rainfed) conditions. No supplemental water was applied; except as necessary or desired, to have a given amount present in the soil at planting and/or to prevent a crop failure. Selection of the amount present in the soil at planting time was left to the discretion of the location.

W2 – represents an amount intermediate between W1 and W3. Half of the amount of irrigation water was applied to W2 as was applied to W3 and its time of application coincided with the W3 treatment.

W3 – represents the well-watered condition, considered the best management regime, providing a high soil water potential within the root zone throughout the season. Water was applied before 50% of the available water was depleted from the root zone, as determined from neutron-probe measurements.

The amount of water needed to maintain well-watered conditions differed with soil properties and with evaporative demand of the atmosphere. It varied with climatic setting among locations and with years within a location.

Nitrogen

N1 – represents the lowest level and consists of 50–60 kg NO_3-N ha^{-1} in the 1.22-m soil depth at planting, the sum of indigenous soil and commercial fertilizer sources.

N2 – represents a low-intermediate level of 100 kg NO_3-N ha^{-1} in the same depth, the sum of indigenous and commercial sources.

N3 – represents the high intermediate level of 160 kg NO_3-N ha^{-1} in the same depth, the sum of indigenous and commercial sources. This amount was to represent the quantity to produce a grain-yield goal of about 4000 kg ha^{-1} when used in conjunction with the best management practices.

N4 – represents the high level of 240 kg NO_3-N ha^{-1} in the same depth and from the same sources.

Soil samples were taken to a depth of 1.22 m, prior to planting, to determine the indigenous amount of NO_3-N present in the rooting zone. To bring the NO_3 content to the desired levels, ammonium nitrate was applied, depending on location facilities, as a band, broadcast before or after planting, or a combination of the two. If leaching was possible, as in the case of water treatment W3, the application was split between a pre- and post-emergence. Other nutrients, e.g. P, K, S or others, were applied as needed.

Cultivars

Two winter wheat cultivars were grown at each location. 'Colt' (C1) was common to all locations, and the locally-adapted cultivars (C2) were 'Norstar' at Lethbridge and Mandan, 'Brule' at Tryon, 'Newton' at Manhattan, and 'TAM 101' at Lubbock. Planting rates were location dependent. In order to provide uniformity between cultivars, records were kept of the number of seeds planted per unit area, the percent germination, weight of at least 200 kernels, and the water content of the grain was measured to determine the mass of seed to plant per hectare. Each year the Colt variety at all locations was supplied from the same seed source.

Cultural practices

Each location maintained a row spacing of 0.15–0.30 m with a north–south planting orientation. Plot width was a minimum of one drill width, or at least 2–3 m, and the length of each plot was left to the discretion of the principal investigator at each location.

All other cultural practices, such as cultivation and the application of herbicides and pesticides, were performed in a timely manner, according to local best-management practices.

MEASUREMENT TECHNIQUES

In order to compare the results from location to location, physical and biological measurement techniques were standardized. This included using the same type of instruments and using the same methods to take data in plots with identical layouts.

Plant sampling

Detailed plant measurements were made from emergence through harvest. Prior to the 3-leaf stage, seedling population was determined by counting the number of plants in 1-m^2 area staked out about 1–2 m from the end of each plot. The same grain drill rows were used in each plot for the sake of continuity. These stakes were left in place for the entire season.

Each week, plant-development stages were determined by the Haun and the Zadok–Chang–Konzak scales (Bauer et al., 1983). Plant canopy height was measured from soil surface to the top of the natural canopy, using an average of 10 plants per plot.

Plants were removed for a measure of dry-matter accumulation in the whole plant and/or from various plant components. Each plot was divided into 4 quadrants for plant sampling. Within each quadrant, 3 adjacent plants were removed and stored in a cool ice chest until they were processed. In the laboratory the 12 plants from a plot were arranged by size. The 3 middle plants were selected by visual estimate of size (a combination of height and weight), and the remaining 9 plants (4 largest and 5 smallest) were separated into green and brown leaves, stems and heads for weighing and drying (at 65–70 °C until dry).

The 3 middle-sized plants were weighed separately and their development stage determined. Plant height was measured from the soil-level mark to the tip of the extended leaves. The number of live stems on each plant was counted, and the plants were separated into flag leaf (after it appeared), green leaves, brown or dead leaves, stems and heads (after heading stage). Areas of the flag leaves, green leaves and dead or brown leaves were measured with a leaf area meter. Each of the plants' components was dried separately at 65–70 °C and weighed. With these data the following information was obtained: tiller number, area of green leaves, area of flag leaf, area of brown leaves, stem dry weight, green-leaf weight, brown-leaf weight, flag-leaf weight, head dry weight, seed dry weight, canopy height and plant height. Before grain physiological maturity, the number of spikes from at least 2 m of row were counted as were the number of spikelets from at least 25 spikes.

After physiological maturity, plants were harvested from at least 3 m^2 in each plot, generally from the area used for spectral reflectance measurements or from the 1-m^2 staked area. Some locations were also harvested with a combine to obtain a larger sample. From processing the harvested plants, information was collected on grain yield, test weight, kernel weight, kernels per spike, spikes m^{-2}, yield per plant, population density and, optionally, grain protein concentrations.

Canopy temperature

Measurements of canopy temperature were made with infrared thermometers (IRT) manufactured by Everest Interscience* or Telatemp*, depending on availability at each location. The IRT's had a bandpass of 8–14 μm and a 4° field-of-view. A minimum of 6 oblique angle measurements were made from the east and west sides of selected plots (a minimum of 2 replications of each treatment was included). The view area was the upper part of the canopy, approximately 2–3 m distant from the observer. In addition, a minimum of 12 readings $plot^{-1}$ were taken with the IRT held in the nadir position with the observer standing on the north side of each plot. Readings from the IRT were recorded on a Polycorder* and then transferred to a computer for processing and analysis.

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*Trade names and company names are for the convenience of the reader and do not imply preferential endorsement of a particular product or company over others.

Daily readings were taken during the week, between 1300 and 1500 h local time when the sun was unobstructed. On days when there were intermittent clouds, measurements were not taken for at least 2 min after a cloud shadow had passed. To insure that an instrument was working properly each day, the reading from the IRT pointing at a standard blackbody was compared with the blackbody readout. The comparison was made just prior to the observer making the field measurement and again immediately upon returning from the field. Agreement within 0.5 °C was deemed acceptable. Prior to the beginning of the experiment, all IRT's were calibrated using a precision blackbody standard at the U.S. Water Conservation Laboratory in Phoenix, AZ.

Spectral reflectance

These measurements were made with a radiometer manufactured by Exotech*, which had 4 spectral bands (450–520, 520–600, 630–690 and 760–900 nm) and a view angle of 15°. Readings were taken from the nadir on the north side of a plot, either holding the instrument by hand or fastening it to a boom mounted on a truck, depending on location. The area viewed was about one row width from the hand-held height and 2–3 rows from the boom.

Readings were taken at least twice each week between 1100 and 1200 h solar time on clear days over at least 2 replicates of each treatment. Data from the radiometer were collected on a Polycorder* and stored in a computer for analysis. To calculate radiance, measurements from a reflectance panel in the field were made every 20–30 min from the beginning of the measurement period to the end. An attempt was made to collect periodic reflectance data from wet and dry bare soil near the field site for comparison purposes.

Soil water content

A neutron probe was used to monitor soil water content at least once a week. The center of the probe's sphere of detection was placed at a depth of 0.15, 0.30, 0.45, 0.60, 0.90 and 1.20 m, as a minimum.

As the access tubes were installed (see Fig. 1 for their position) soil cores taken at each increment were placed in plastic bags. These cores were used for the determination of soil water content for the neturon-probe calibration, for the determination of bulk density, and for further soil analyses. In the laboratory, moisture characteristic curves were determined at −0.01 or −0.033 MPa, for coarser and finer soil textures, respectively, and −0.1, −0.5, −0.8, −0.9 and 1.5 MPa. The upper limit of available water was taken as one of the first two values, while the lower limit was taken at −1.5 MPa or the minimum soil water-depletion point, at the discretion of the location. Also, each location determined the method of applying irrigation water to the plots.

Standard weather stations

Weather parameters were recorded at each location by means of Campbell Scientific* CR21 or CR21X datalogger connected to the following sensors: a Phys-Chem* air temperature/humidity probe at 2-m height, a Met-one* anemometer (2 m) and wind vane (2 m), Li-Cor* silicon pyranometers (shaded and unshaded at 2 m), a Li-Cor* PAR sensor (2 m), a soil temperature (0.05-m depth) and a Sierra-Misco* tipping bucket raingage. Sensors were sampled once each minute to provide averages and/or totals for hourly and daily periods. All sensors were calibrated prior to the start of the experiment. The standard precautions for choosing a representative site and maintaining that site during the experiment were observed. Data from each site were transmitted to a central location for processing and collation. For the Manhattan and Tryon sites, the data were collected in near-real time, while the other sites reported at the end of the season.

DATA STORAGE

Categories

The data for each site were separated by year into general categories. Data records were coded to identify the site, cultivar, nitrogen and irrigation treatments, time of measurement and other information as needed. Briefly, the data set includes the folowing measurements.

Soil characteristics
In this category the sites are characterized by site name, state or province, elevation, latitude, longitude, soil water holding capacity and bulk density.

Soil moisture measurements
The volumetric water content is given to a depth of at least 210 cm in the following layers: 0–15, 15–30, 30–45, 45–60, 60–90, 90–120, 120–150, 150–180 and 180–210 cm.

Canopy temperatures
Included in this category are the mean and standard deviation of readings from east and west directions and the nadir view respectively. These quantities were formed from a minimum of 6 measurements from each view direction and 12 from the nadir view.

Reflectance data
The mean and standard deviation of readings taken with truck-mounted or hand-held multi-spectral scanners in the Landsat bands 450–520, 520–600, 630–690 and 760–900 nm are included in this category.

Soil classification
This category was used to report the scientific classification of the soil.

Irrigation amounts and dates
The amount of water (cm) applied to each treatment is given for each date and treatment.

Fertilizer data
The nitrogen fertilizer (kg ha^{-1}) added to maintain each replication at desired levels is reported in this category.

Daily weather data
Measurements of daily maximum and minimum temperature (°C), total precipitation (mm), average relative humidity (%), solar radiation (MJ m^{-2}), soil temperature (°C) at 10 cm and wind run (km day^{-1}) are archived for each study site.

Planting information
The planting date for the various treatments and cultivars is recorded in this category.

Plants-phenology
This category includes estimates of phenological stage on various dates using both the Haun and Zadoks–Chang–Kouzak scales as well as a narrative description when available.

Plants-canopy height
The measurements of canopy height (cm) were recorded for the various treatments and are included in this data category.

Plants-seedling population density
The row width and average plant density (plants ha^{-1}) are given in this format.

Plants-parts
Measurements resulting from sampling of plant parts are recorded. Possible entries include: tiller number, area of green leaves and flag leaf, and the dry weight of the stems, green leaves, dead leaves, head and seed. The canopy height, plant height and percent lodging are also included.

Plants-harvest data

In this category the yield (kg ha^{-1}), weight by unit standard volume (kg ha^{-1}), protein content (%), kernel weight (g per 100 kernels) and spike density (m^{-2}) are given.

Data availability

Data are available to interested parties and may be ordered by specifying the year(s) and site(s) (requests for individual data categories will not be honored). Send one double-sided, double-density $5\frac{1}{2}$" diskette per site per year, or 10 for the complete data set to: Center for Agricultural Meteorology and Climatology, Attention: NAGP Experiment, 237 L. W. Chase Hall, University of Nebraska, Lincoln, NE 68583-0728 U.S.A.

In addition to the diskettes, please send a self-addressed, postage paid envelope for the return of the diskettes.

Questions concerning the data should be addressed to the person at a particular location for clarification.

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